Unity assumption between face and voice modulates audiovisual temporal recalibration

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Abstract

Audiovisual temporal recalibration refers to a shift in the point of subjective simultaneity (PSS) between audio and visual signals triggered by prolonged exposure to asynchronies between these signals. Previous research indicated that the spatial proximity of audiovisual signals can be a determinant of which pairs of signals are temporally recalibrated when multiple events compete for recalibration. Here we show that temporal recalibration is modulated by an observer's assumption that the audiovisual signals originate from the same unitary event ("unity assumption"). Participants were shown alternating face photos and voices of the male and female speakers. These stimuli were presented equally spaced in time, and the voices were presented monaurally through headphones, such that no spatiotemporal-based grouping was implied for these stimuli. There were two conditions for the stimulus sequence in the adaptation phase: one in which a face photo always preceded its corresponding voice within each pairing of audiovisual stimuli (i.e., multiple repetitions of the sequence: female voice – male face – male voice – female voice), and the other one in which the corresponding voice always preceded its face photo. We found a shift in the PSS between these audiovisual signals towards the temporal order for the same gender person. The results show that the unity assumption between face photos and voices affects temporal recalibration, indicating the possibility that the brain selectively recalibrates the asynchronies of audiovisual signals that are considered to originate from the same unitary event in a cluttered environment.

Keywords: temporal recalibration, adaptation, unity assumption, multisensory synchrony

Declarations

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Conflicts of interest / Competing interests. None.

Ethics approval. The project was approved by the Ethical Committee of the Department of Psychology, The University of Tokyo.

Consent to participate. Informed consent was obtained from all participants.

Consent for publication. Informed consent was obtained from all participants and authors.

Availability of data and materials. The data that support the current study are available at https://osf.io/q2wae/?view_only=b6a2e58ccf164bba9caa5ec088043d8d.

Code availability. The code that supports the current study is available from the corresponding author upon reasonable request.

Authors' contributions. K.U. and K.Y. designed the experiments, analyzed the data, and discussed the results. K.U. performed the experiments and wrote the manuscript. K.Y. refined the manuscript.

Introduction

Natural events generally comprise information perceived via multiple modalities. Despite the differences in naturally occurring lags in the arrival and neural processing times of different modalities, observers perceive synchrony among these multimodal signals. This suggests that the perceptual system has functions for addressing temporal disparities in signals and forming a coherent representation of the world (see King, 2005; Vroomen & Keetels, 2010, for review). One of these functions is audiovisual temporal recalibration: shifts in subjective simultaneity between audiovisual signals based on the recent history of sensory exposure. Previous studies have shown that prolonged exposure to asynchronies between auditory and visual signals modulates the point of subjective simultaneity between the two signals such that the asynchronous signals seem more synchronous (Fujisaki, Shimojo, Kashino, & Nishida, 2004; Vroomen, Keetels, De Gelder, & Bertelson, 2004). Temporal recalibration has been observed not only using simple audiovisual stimuli such as flashes and beeps but also using more complex stimuli such as speech stimuli (Roseboom & Arnold, 2011; Roseboom, Kawabe, & Nishida, 2013; Vatakis, Navarra, Soto-Faraco, & Spence, 2007, 2008; Yuan, Bi, & Huang, 2015).

Previous investigations of temporal recalibration have usually focused on isolated pairs of audiovisual stimuli. In these studies, temporal recalibration was considered to occur regardless of the spatial proximity of the audiovisual stimuli (Keetels & Vroomen, 2007). However, more recent studies have suggested that temporal recalibration depends on the relationship between audiovisual adaptors when multiple events compete for recalibration (Ikumi & Soto-Faraco, 2014; Yarrow, Roseboom, & Arnold, 2011). Yarrow et al. (2011) demonstrated that temporal recalibration is facilitated by spatial grouping between the audiovisual adaptors when

they are not temporally isolated. In their study, participants were exposed to a train of alternating flashes and beeps equally spaced in time from the left and right sides of the fixation. For each of the two conditions, the order between flashes and beeps was constant on either side of the fixation: for the light lagging condition, the adaptation train contained multiple repetitions of the sequence left tone – left light – right tone – right light, and for the light leading condition, it was left tone – right light – right tone – left light. They found that the point of subjective simultaneity (PSS) shifted toward the temporal relationship implied by the spatial-based grouping, and suggested that spatial cues modulate temporal recalibration when audiovisual stimuli are not grouped on the basis of temporal proximity. Ikumi and Soto-Faraco (2014) tested temporal recalibration following an adaptation phase where two opposing audiovisual asynchronies were present (i.e., flash – sound – flash). They found that the PSS was different based on whether observers had focused their visual attention to the former flash or the latter flash, suggesting that selective attention modulates the direction of temporal recalibration.

These findings raise the possibility that temporal recalibration is modulated by the assumption that the audiovisual signals are considered to originate from the same unitary event. Temporal recalibration contributes to integrating the auditory and visual signals that have arrived with a certain delay, which can be beneficial when the two signals originated from the same unitary audiovisual event. On the other hand, when the two signals originated from two separate unimodal events, temporal recalibration may lead to false causal inferences in multimodal perception. Therefore, in order to appropriately integrate many audiovisual signals in the external world, it would be necessary for the brain to selectively recalibrate time lags for audiovisual signals that are considered to originate from the same unitary event.

Previous studies have indicated that such an assumption, generally referred to as the “unity assumption” (Welch & Warren, 1980), facilitates integrating two or more signals from different modalities into a single perceptual event (see Chen & Spence, 2017; Chen & Vroomen, 2013; Spence, 2007, for review). The integration of asynchronous audiovisual stimuli can be modulated by the unity assumption between auditory and visual speech stimuli (Vatakis, Ghazanfar, & Spence, 2008; Vatakis & Spence, 2007), and by the unity assumption based on crossmodal correspondences (Parise & Spence, 2008, 2009; Orchard-Mills, Van der Burg, & Alais, 2016; though see Keetels & Vroomen, 2011). In consideration of these findings, it is possible that temporal recalibration is facilitated by the unity assumption between the audiovisual adaptors when multiple events compete for recalibration.

To investigate this possibility, we used audiovisual stimuli (voices and face photos) of a female and a male speaker, and manipulated the unity assumption between audiovisual adaptors based on the congruency of the faces and voices. Similarly to the experiment in Yarrow et al. (2011), participants in our study were exposed to a train of alternating visual stimuli (face photos) and auditory stimuli (voices) equally spaced in time. The auditory stimuli were presented monaurally through headphones, so that no cues of spatial congruency existed in the adaptation sequence. However, the gender congruency of the face photos and voices could be used as a cue to modulate the direction of temporal recalibration. We found that the direction of temporal recalibration was dependent on the constant asynchrony of face photos and voices from the same gendered person, which suggests that the unity assumption facilitates audiovisual temporal recalibration.

Method

Participants

We recruited 32 participants (14 women, 18 men; age: $M = 21.4$ years, $SD = 1.9$ years). All participants had normal or corrected-to-normal vision and hearing, and were naïve about the study. Participants were compensated with either course credit or 2,040 Japanese yen (approximately \$20).

This sample size ($N = 32$) was determined to have sufficient power to detect moderate effects as follows. To detect the effects of $d_D = 0.6$ with $\alpha = .05$ (two-tailed) and power of 90%, the required sample size is 32 (calculated by G*Power Version 3.1; Faul, Erdfelder, Buchner, & Lang, 2009). The desired number of participants was a multiple of 8 for counterbalancing of stimulus conditions.

The project was carried out in accordance with the guidelines of the Declaration of Helsinki and was approved by the Ethical Committee of the Department of Psychology, The University of Tokyo. Informed consent was obtained from all participants.

Apparatus

We ran the experiment on a PC using Psychophysics Toolbox (Brainard, 1997; Pelli, 1997) on MATLAB (MathWorks). Visual stimuli were presented on a calibrated color monitor (Mitsubishi Diamondtron VX920), with a resolution of 1024×768 pixels and refresh rate of 100 Hz. Participants viewed the monitor binocularly from a distance of 57 cm, with their head resting on a chinrest, in a quiet dark room. Auditory stimuli were presented monaurally through headphones (Sennheiser HDA200). Accurate stimulus timing was confirmed using a digital oscilloscope. Participants responded using a numeric keypad.

Stimulus

The stimuli consisted of face photos and voices of two native Japanese speakers, one female and one male. These audiovisual stimuli were produced in the following way.

We recorded movies of the two speakers saying “a”, using a Panasonic Handycam HC-VX992M and an Audio-Technica microphone AT9941. Each of the two auditory stimuli was produced by clipping from the original movie (16-bit sample size, mono) so that the duration was 120 ms. These stimuli were normalized to a peak sound intensity of 70 db SPL and contained 10 ms linear ramps at onset and 30 ms linear ramps at offset in order to match the timing of the volume change between them. Each of the two visual stimuli (face photos) was produced by clipping the image of the moment of utterance in the original movie.

Visual stimuli were presented within an oval aperture ($4.5^{\circ} \times 6.0^{\circ}$ of visual angle) centered 3.7° on the right or left of the central fixation cross. For half of the participants, the male face was presented on the left and the female face on the right throughout the experiment, and for the other half, the arrangement was reversed.

Procedure

A block of trials is depicted in Figure 1a. Participants were instructed to maintain fixation on the central fixation cross throughout the entire experiment. Each block consisted of an adaptation phase and a test phase, and began with a 60 s initial adaptation phase. Each participant completed four blocks of trials.

In the adaptation phase, a pattern of two visual stimuli and two auditory stimuli was presented repeatedly. There were two adaptation conditions (face leading and voice leading), as in the experimental design in Yarrow et al. (2011), and the conditions were

changed for each block. The adaptor sequence in the face-leading condition is shown in Figure 1b. For the face-leading condition, the adaptation train contained multiple repetitions of the sequence female voice – male face – male voice – female voice. Thus, within each pairing of audiovisual stimuli for the same participant, a visual stimulus (face photo) was always presented before an auditory stimulus (voice). For the voice-leading condition, the sequence was female voice – female face – male voice – male face, so an auditory stimulus was always presented before a visual stimulus within each pairing. Importantly, the interval between audio and visual stimuli was physically identical (80 ms) in both conditions to remove temporal cues to grouping for our bisensory events (cf. Yarrow et al., 2011). The duration of each audiovisual stimulus was 120 ms, so the audiovisual stimuli were presented at a constant rate of 5 Hz alternating between face photos and voices.

Following adaptation, participants completed the test phase (Figure 1c). Participants were required to judge whether the test audio and visual stimuli had been synchronous (i.e., simultaneous) or asynchronous by pressing one of two computer keys (“4” or “6” on the numeric keypad). The key assignments were counterbalanced across participants. The stimulus onset asynchronies (SOAs) between these two stimuli were manipulated across 11 levels (± 400 , ± 320 , ± 240 , ± 160 , ± 80 , 0 ms; negative numbers indicating an auditory stimulus presented before a visual stimulus). Pairs of the same person’s face and voice were used as audiovisual stimuli in the test phase: pairs of the male face and voice were presented in half of the trials in each block, and in the other half, pairs of the female face and voice were presented. Before each test trial, a top-up adaptation sequence was presented for 5 s (i.e., 6.25 repetitions of the four-stimulus pattern). Subsequent to this, participants were informed that they would be required to respond to the next presentation by a change in the central fixation cross from light grey

to red. For each block, 110 test trials were required for each participant: 11 SOAs $\times$ two types of pairings of stimuli in the test phase $\times$ 5 occasions, all in a randomized order. In the middle of each block (every 55 trials), participants were able to take a break for a few minutes. A 60 s adaptation phase was presented at the start of each block, and also after each break.

The order of adaptation conditions was counterbalanced across participants. For half of the participants, the order of the conditions was face leading – voice leading – face leading – voice leading, and for the other half of, it was voice leading – face leading – voice leading – face leading. After each block, participants took a 5-min break.

Figure 1. (a) Timeline of the experimental procedure in each block. (b) Schematic illustration of the adaptor sequence in the face-leading condition. Audio and visual stimuli were presented at a constant rate of 5 Hz alternating between faces and voices, with the grouping implied by the identity of each person (shown as dotted lines). (c) The procedure of a single test trial.

Results

For each of the two adaptation conditions with each participant, we fitted the data of the proportions of simultaneous responses as a function of the SOA on test trials with Gaussian functions. The point of subjective simultaneity (PSS; the mean of the distribution), amplitude, and synchrony bandwidth (the standard deviation of the distribution) were estimated. A participant whose data had a goodness of fit (adjusted R^2) to the fitted function below 0.5 in one of the conditions was discarded from the analyses. However, when we included this participant in the analysis, our main conclusions did not change.

The results of this experiment are illustrated in Figure 2. Standard two-tailed parametric tests were used to assess differences in the three parameters across the adaptation conditions. We found that the PSS's in the face-leading condition were significantly larger than those in the voice-leading condition (-6.35 ms and -18.45 ms respectively, $t(30) = 2.35$, $p = .026$, $d_D = 0.42$), indicating that the PSS was shifted in the direction of the asynchrony between audiovisual adaptation stimuli grouped by the gender of the stimuli. We also conducted paired-sample t tests on the amplitude and synchrony bandwidth data of the fitting functions. There was no significant difference in the amplitude between conditions (1.05 and 1.07 respectively, $t(30) = 1.30$, $p = .203$), or in the synchrony bandwidths between conditions (183.63 ms and 179.03 ms respectively, $t(30) = 0.93$, $p = .361$).

Figure 2. (a) Proportions of simultaneity judgments averaged across all participants as a function of stimulus onset asynchrony (SOA) for each adaptation condition (face leading or voice leading). Negative SOAs indicate that audition was leading, whereas positive SOAs indicate that vision was leading. (b) Mean points of subjective simultaneity (PSSs) for each condition. Error bars represent standard error of the mean.

Discussion

We found that the constant asynchrony of face photos and voices with the same gender modulates the direction of temporal recalibration. The audiovisual stimuli were presented at a constant rate of 5 Hz alternating between face photos and voices, so these stimuli would not be grouped into bimodal pairs on the basis of temporal properties. In addition, because the auditory stimuli were presented monaurally through headphones, spatial congruency between audiovisual stimuli, such as in Yarrow et al. (2011), would not exist in the adaptation sequence. The result that the PSS shifted in response to two types of adaptation even though spatiotemporal cues were eliminated indicates that the unity assumption between face photos and voices (in this case based on shared gender)

affects temporal recalibration. This is consistent with the view that the unity assumption facilitates the integration of multisensory signals (Chen & Spence, 2017; Chen & Vroomen, 2013; Spence, 2007).

The difference in PSS between the two adaptation conditions in the current study was 12.1 ms (95% $CI = [1.5, 22.7]$), which was much smaller than that found in the previous study examining the effect of spatial congruency using a similar procedure (36.5 ms; Yarrow et al., 2011). One possible explanation for this is that the unity assumption between audiovisual stimuli used in our study was not sufficient. Previous studies reported that the unity assumption (audio-visual syllable congruency or speaker identity) between asynchronous auditory and visual speech stimuli facilitates multisensory integration (Vatakis et al., 2008; Vatakis & Spence, 2007). In these studies, videos of human faces were used as visual stimuli. However, we used face photos of a woman and a man instead of videos because the duration and onset timing of the audiovisual stimuli needed to be aligned in order to avoid temporal proximity-based grouping. This may have made it more difficult to assume unity between the audiovisual stimuli, and thus weakened the effect of the unity assumption on temporal recalibration. Another possibility is that the effect of the unity assumption on temporal recalibration may be inherently weaker than the effect of spatial grouping. As mentioned in the Introduction, Ikumi and Soto-Faraco (2014) showed a shift of PSS based on whether observers had focused attention to the former flash or the latter flash in the adaptation sequence flash – sound – flash. The reported differences in PSS between these two adaptation conditions were 21.6 ms (Experiment 1) and 15.2 ms (Experiment 2), which were also smaller than 36.5 ms (from Yarrow et al., 2011). This suggests the possibility that the cognitive factors, such as the unity assumption or selective attention (Ikumi & Soto-Faraco, 2014), are less effective for determining the

direction of temporal recalibration than low-level structural factors, such as spatial grouping (Yarrow et al., 2011).

Our results suggest that the brain selectively recalibrates the asynchronies of audiovisual signals that are considered to originate from the same unitary event, in our experiment based on gender. This is consistent with previous findings that temporal recalibration occurs for each stimulus pair (Heron, Roach, Hanson, McGraw, & Whitaker, 2012; Roseboom & Arnold, 2011; Roseboom et al., 2013; Yuan, Li, Bi, Yin, & Huang, 2012). These studies demonstrated that PSSs were concurrently shifted in the direction of the adapted asynchrony for each of the two isolated stimulus pairs, indicating that people can simultaneously adapt to two audiovisual timing relationships. Considering these findings together with the results of our current study, people may concurrently estimate which audiovisual stimuli originate from the same source and recalibrate the time lag of each of the pairs of audiovisual signals.

One unsolved question is whether the assumption that the two stimuli originated from two separate unimodal events can also modulate observers' judgments of simultaneity. Some studies raise the possibility that, in such a situation, the point of subjective simultaneity shifts toward the direction opposite to the temporal recalibration (Miyazaki, Yamamoto, Uchida, & Kitazawa, 2006; Yamamoto, Miyazaki, Iwano & Kitazawa, 2012). Miyazaki et al. (2006) found that exposure to asynchronies between two tactile stimuli modulates the point of subjective simultaneity such that the asynchronous signals seem more asynchronous; they referred to this phenomenon as Bayesian calibration. Yamamoto et al. (2012) found that Bayesian calibration was also observed in pairs of audiovisual stimuli only when temporal recalibration was cancelled. Given these findings, it is possible that temporal recalibration does not occur within pairs of audiovisual stimuli for which no unity is assumed, and instead Bayesian

calibration occurs. In the current study, it was unclear whether Bayesian calibration occurred within incongruent pairs of audiovisual stimuli (i.e., male face – female voice, female face – male voice) in addition to temporal recalibration in congruent pairs (i.e., male face – male voice, female face – female voice). Further investigation is needed to clarify the relationship between the causal inference of audiovisual signals and changes in simultaneity perception.

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Open Practice Statements

The data and materials that support the current study are available at https://osf.io/q2wae/?view_only=b6a2e58ccf164bba9caa5ec088043d8d. None of the experiments were preregistered.

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